INTERNATIONAL JOURNAL OF MARITIME TECHNOLOGY

IJMT Vol.16/ Summer 2021 (73-85)

Available online at: www. ijmt.ir

Impact of a set of XBeach calibration factors on the behavior of cross-shore profiles in medium-term timescales: A case study

Ali Shams Derakhshan[1], Mahdi Adjami[2*]

[1] MSc Student, Faculty of Civil Engineering, Shahrood University of Technology, Shahrood, Iran; ali_shdr@yahoo.com
[2] Assistant Professor, Faculty of Civil Engineering, Shahrood University of Technology, Shahrood, Iran; adjami@modares.ac.ir*

ARTICLE INFO

Article History:
Received: 12 Nov. 2021
Accepted: 23 Apr. 2022

Keywords:
Sensitivity Analyzes
Sandy beach
Sedimentation
Bed level change
Process-based modeling

ABSTRACT

XBeach is designed to model nearshore area in storm conditions and needs adjustments to be used for longer periods. One way to implement this model on a medium- or long-term time scale is to take the model through a calibration step. Selecting the right calibration factors amongst several parameters can be challenging. In this study, ten factors were selected based on the literature review to determine the extent and nature of their impact on the transformation of the sandy profiles of Zarabad fishery harbor in seven months (2006.02.20 to 2006.09.23). By 2DH modeling, the results are represented by two profiles from the study area. Six of the ten selected parameters had a significant effect on the behavior of the profiles, and the results of seven out of ten parameters showed a convergence point in their profiles. As a result of this study, it is possible to move more consciously and expedite the calibration process of further studies. Of course, changing the particle size, the beach slope, the modeling duration, and the energy level of the incoming waves in the area may lead to different results, which can lead to further studies.

1. Introduction

1.1. Background

Currently, several free and commercial software and models, such as Mike software [1], SBeach [2], XBeach [3], Delft3D [4], CROSMOR [5], etc., can predict the behavior of coastal sediments, each with its advantages and disadvantages.

XBeach is a process-based numerical model that has been used repeatedly by many companies and researchers worldwide to determine nearshore morphological changes. Compared to other models, XBeach has a more complete set of equations for cross-shore processes. For example, return flow, wave asymmetry, wave rollers, and long waves, unlike Delft3D, are included in XBeach. Due to the inclusion of long waves, XBeach is particularly suitable for modeling near-shore processes, while Delft3D is more widely used in larger domains [6].

In recent years, some researchers ([7], [8], [9], [10], [11], [12]) have been able to use XBeach for modeling beyond storm-scale periods, such as years and decades, which have provided scientists with a wide range of studies. XBeach has about 250 different model settings; Approximately 150 of these settings represent numerical and physical behavior, and another 100 are used for specific cases [3]. Nine XBeach parameters have a significant impact on the model results; These parameters are optimized for one-dimensional storm models on the Dutch coast and are called WTI settings (Table 1) [13].

Here are some of the results of the literature review regarding the long-term use of the XBeach model:

- The results of previous studies show that with some modifications, the XBeach model can be employed for long-term simulations [8–14].
- A two-dimensional model can be used to approximately include long-shore sediment transport [3].
- The "stationary mode" is better suited for long-term modeling with mild wave conditions [9].
- Asymmetry and skewness coefficients are among the most important calibration parameters in this model [9–11].
- In assessing the results, it should be kept in mind that since the model lacks an aeolian transport module, it usually shows excessive coastal erosion [9].

1.2. Area of interest

The construction of Zarabad Fishery Harbor completed in 2006. The Harbor is located at Sistan and Balouchestan Province, Iran (25˚23́N 59˚36́W), which is under constant attacks of south and southeast waves during monsoon season and Shamal winds/waves in winter. As a result of the insufficient space behind the main breakwater to block the high rate of westward longshore sediment transport, a significant volume of sedimentation was observed at the Harbor entrance in a short period after construction. The large sedimentation forced the authorities to organize a regular monitoring plan of periodic hydrography surveys from 2006 to 2008. A long jetty, started at the turning point of the main breakwater, was later (2008-2014) constructed to increase the space and to stop the sediment bypassing (Figure 1) [15].

Figure 1. Zarabad fishery harbor location and layout

1.3. Objectives

The main purpose of this study is to provide further details on the calibration part of another research [16], and to investigate the effect of the selected parameters (facSk, facAs, alpha, wetslp, dryslp, beta, gammax, gamma, bedfriccoef, hmin) and the reason of these effects on the final shape of the cross-shore profiles to streamline the future studies and calibrations.

1.4. Outline

In section 2, first, some details of the modeling methodology are presented and the research process is discussed, then section 3 presents the results of each parameter evaluation and discusses the results. Finally, Section 4 includes a final and concise evaluation report of all the parameters and presents the applications of the findings, the limitations of the study, and their applicability extent.

2. Methodology

As mentioned before, this study details the results of another research calibration section, and further modeling description can be found in that article [16]. However, the following cases can be mentioned briefly:

- Considering the greater number of available profiles on the right side of the harbor and the importance of the location of the profiles No. 1 and 2, these two profiles were selected to represent the area (Figure 2).

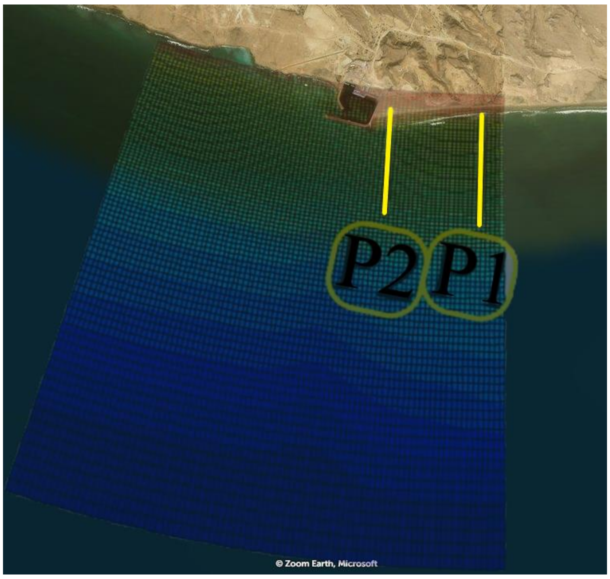

Figure 2. Model grid scheme and cross-shore profiles selected to represent the study area

- The particle median diameter (d50 = 90µm) was determined based on sampling and sieve analysis tests on sediments accumulated around the harbor.
- The nautical convention for the directional grid of input waves (thetanaut = 1) was used for modeling.
- XBeach has a variety of settings for determining the wave boundary condition [3]; The (wbctype = stat_table) option was used for this research, considering the available wave data and the stationary condition assumption.
- The wave data used in this study were obtained from the Wave Watch III model, which became the required XBeach format after making the necessary changes.
- All wave series were randomly arranged to avoid the chronological effects of seasons.
- The (tideloc = 1) mode was used for the tidal conditions in the model, meaning that the specified tidal record is specified on all four domain corners and interpolated along the boundaries.
- Based on the literature review, 10 parameters were selected for this study (Table 1)
- The duration of the modeling was 7 months (2006.02.20 to 2006.09.23).
- In the sensitivity analysis, while keeping the other parameters constant (relative to the reference model), the desired parameters have been changed in their specific range (according to Table 1).

Table 1. WTI settings, XBeach default settings, and the selected parameters for this study [3,13].

No.	Parameter	WTI (value)	Default value	Selected	Description	Range
1	**facSk**	√ (0.375)	0.100	√	Wave skewness factor	0.0~1.0
2	**facAs**	√ (0.123)	0.100	√	Wave asymmetry factor	0.0~1.0
3	**alpha**	√ (1.262)	1.000	√	wave dissipation coefficient	0.5~2.0
4	**wetslp**	√ (0.260)	0.300	√	Critical avalanching slope under water.	0.1~1.0
5	**dryslp**	-	1.000	√	Critical avalanching slope above water.	0.1~1.0
6	**beta**	√ (0.138)	0.100	√	Breaker slope coefficient in roller model	0.05~0.3
7	**gammax**	√ (2.364)	2.000	√	Maximum ratio wave height to water depth	0.4~5.0
8	**gamma**	√ (0.780/0.541)	0.550	√	Breaker parameter in Baldock / Roelvink formulation	0.4~0.9
9	**bedfriccoef**	-	0.010	√	Bed friction coefficient	3.5e-05~0.9
10	**hmin**	-	0.200	√	Threshold water depth above which stokes drift is included	0.001~1.0
11	**cf**	√ (0.001)	0.003	-	Dimensionless friction coefficient	-
12	**fw**	√ (0.000)	0.000	-	Short wave friction coefficient	-

3. Results and Discussion

The results of the study are presented in the form of two selected profiles for all the parameters mentioned above. Changed zones are represented by rectangles with green dotted lines, and the type of change in the range of each parameter (from low to high) is indicated by green arrows. Also, the turning points of these changes (if any) are marked with a red star.

3.1. Skewness and Asymmetry

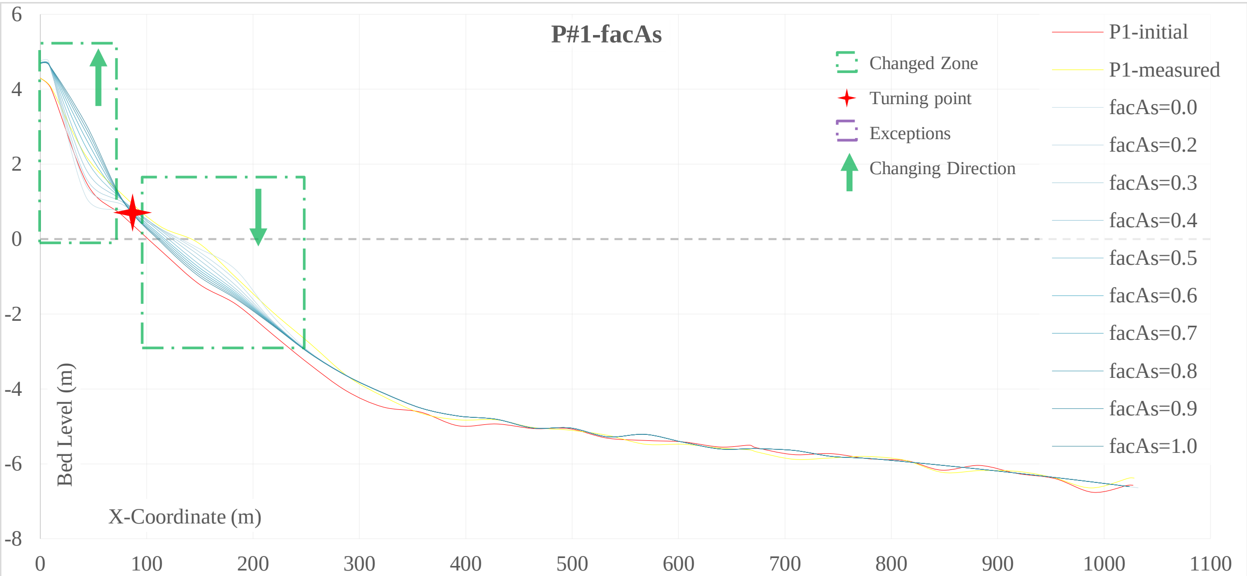

Figure 1. Results of the facAs parameter sensitivity analysis in the 7 months (2006.02.20 to 2006.09.23) for profile #1

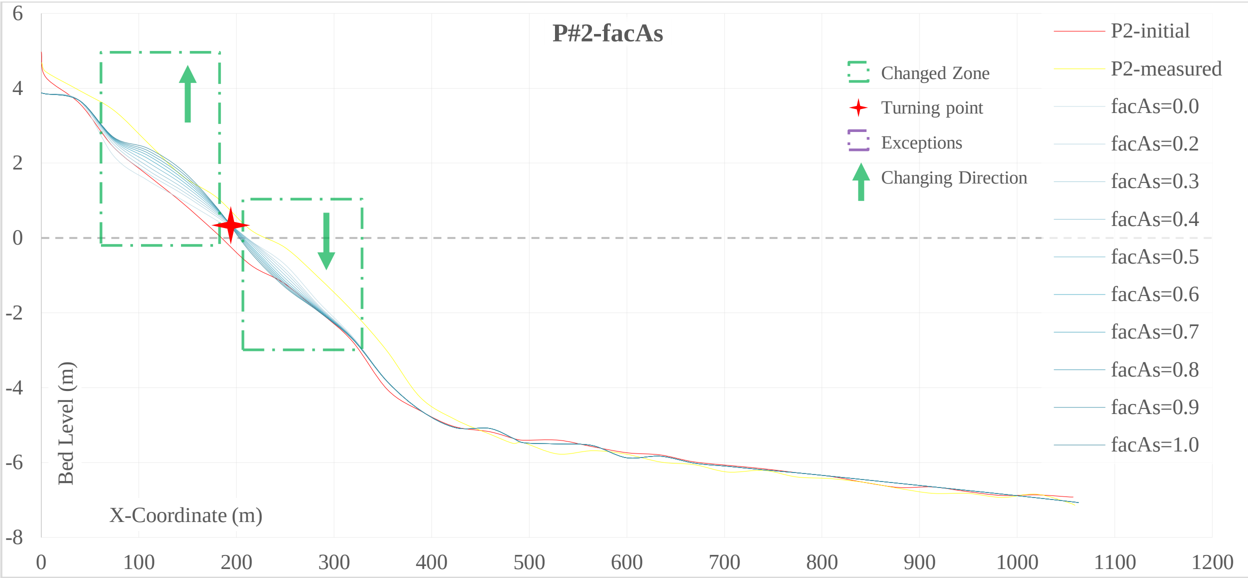

Figure 2. Results of the facAs parameter sensitivity analysis in the 7 months (2006.02.20 to 2006.09.23) for profile #2

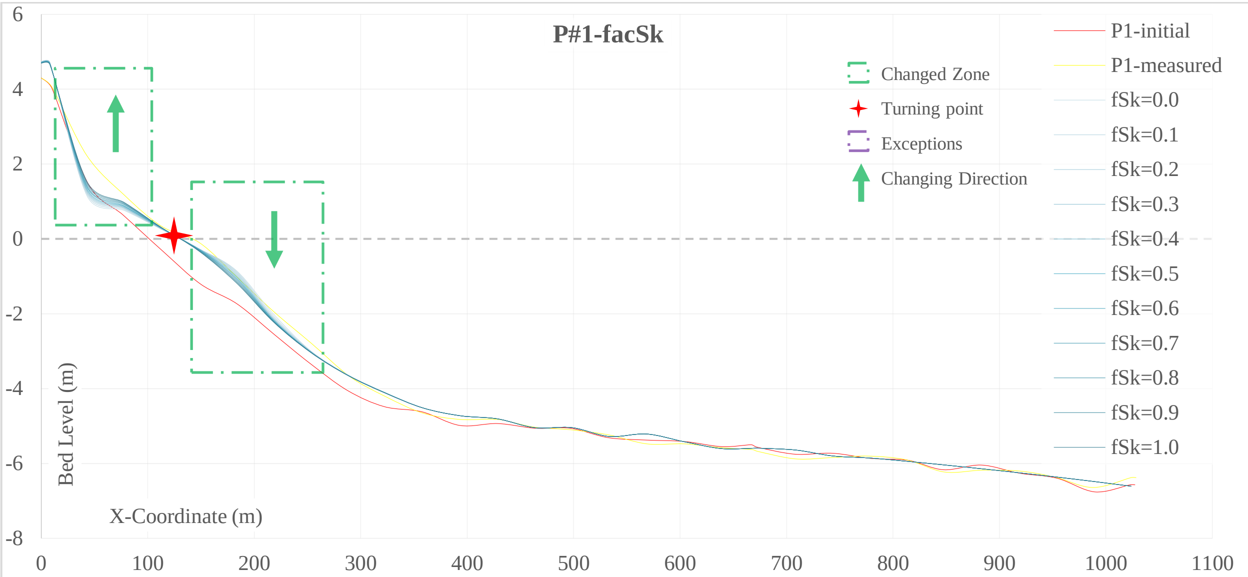

Figure 3. Results of the facSk parameter sensitivity analysis in the 7 months (2006.02.20 to 2006.09.23) for profile #1

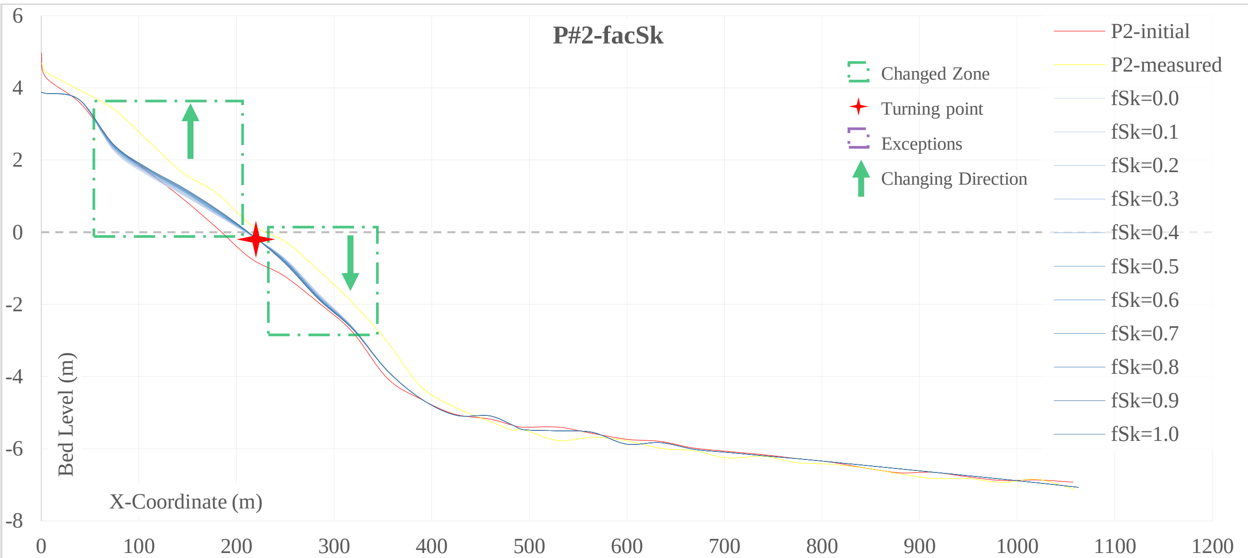

Figure 4. Results of the facSk parameter sensitivity analysis in the 7 months (2006.02.20 to 2006.09.23) for profile #2

The factors of asymmetry and skewness can increase sediment transfer to the shore [17].
According to Figures (3 and 4) of the Sensitivity Analysis of the Asymmetry Factor, a point of convergence can be seen in both figures as shown by the red star. It was generally observed that as the value of the asymmetry factor increases, sediment accumulation at the top of the red star increases, and the volume of sediment at the bottom of this star decreases, thereby reducing the coastal dune erosion rate.
The observations mentioned above was also correct for the skewness parameter, except that this factor had less effect on the deformation of the profile; this can be due to the fact that the skewed wave can transfer sediments both offshore and onshore according to the existing conditions [18].

3.2. alpha

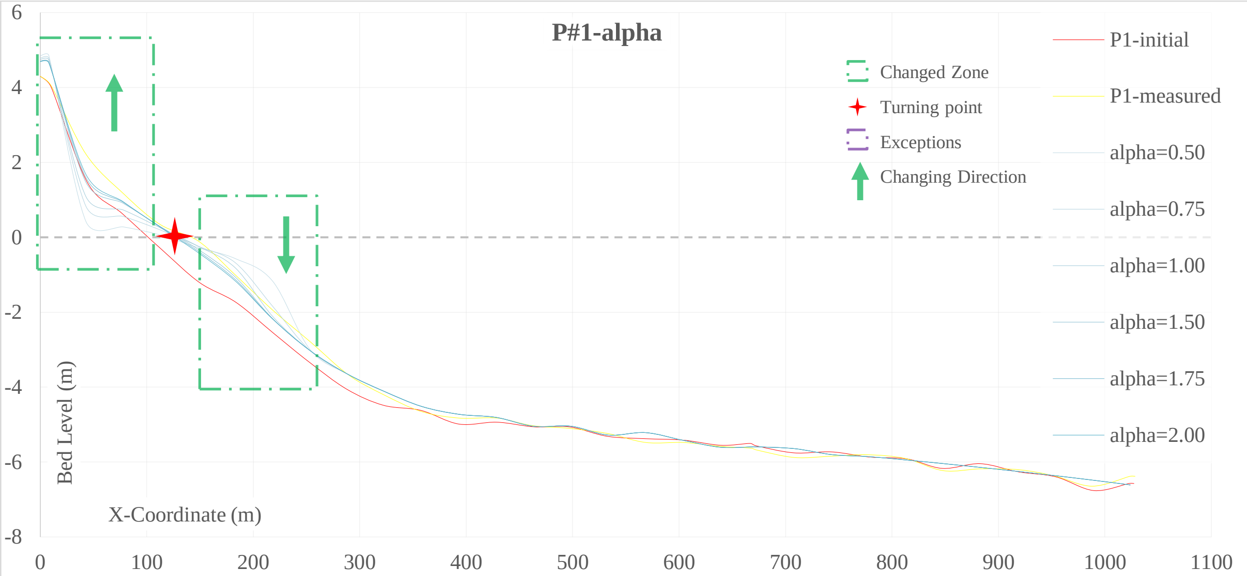

Figure 5. Results of the alpha parameter sensitivity analysis in the 7 months (2006.02.20 to 2006.09.23) for profile #1

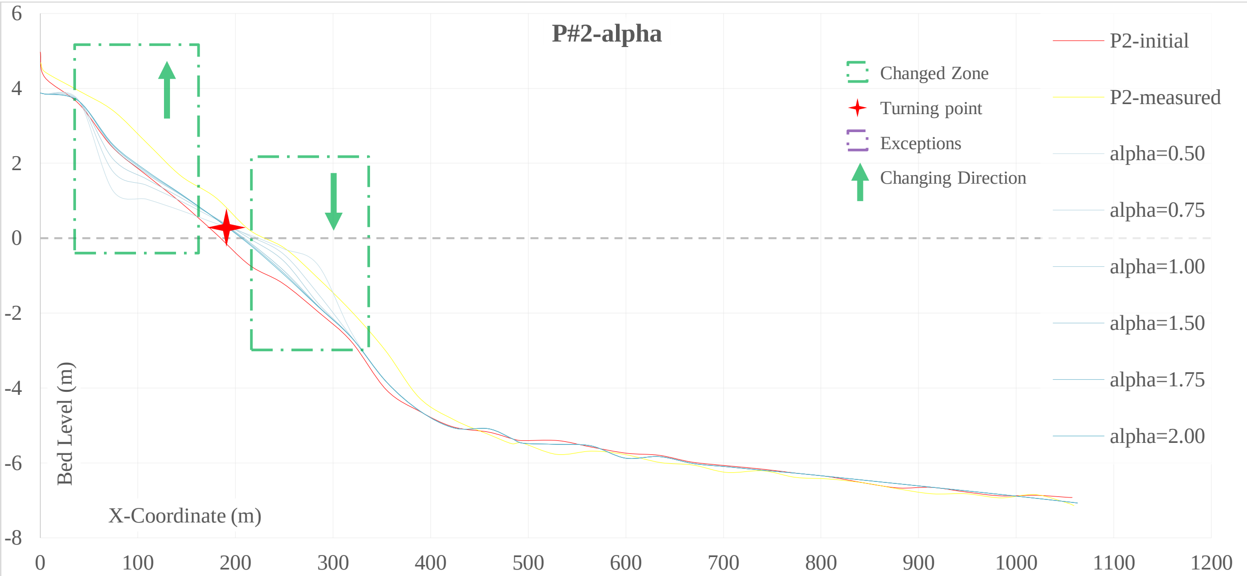

Figure 6. Results of the alpha parameter sensitivity analysis in the 7 months (2006.02.20 to 2006.09.23) for profile #2

As this parameter increases, the amount of deposition at the top of the convergence point increases, as can be seen in Figures 7 and 8. This can be explained by Baldock formulation (Equation 1, [19]); given that as this coefficient increases, the amount of wave energy loss also increases, so the wave energy is not sufficient to wash down the sediments above the convergence point. Therefore, the lower the coefficient, the more energy the wave has, and the higher the erosion of the coastal dune. It can also be noticed that an extreme decrease in this coefficient results in the formation of a bar below the convergence point and a berm above it.

$$\bar{D}_w = \frac{1}{4}\alpha Q_b \rho g f_{rep}(H_b^2 + H_{rms}^2)$$
$$Q_b = exp\left[-\left(\frac{H_b^2}{H_{rms}^2}\right)\right], \; H_b = \frac{0.88}{k}tanh\left[\frac{\gamma kh}{0.88}\right] \quad (1)$$

In this breaking formulation, the fraction breaking waves Q_b and breaking wave height H_b are calculated differently compared to the breaking formulations used for the non-stationary situation. α is applied as wave dissipation coefficient, f_rep represents a representative intrinsic, H_rms is the root-mean-square wave height, ρ represents the water density, g is the gravitational constant and D_w is the wave breaking.

3.3. beta

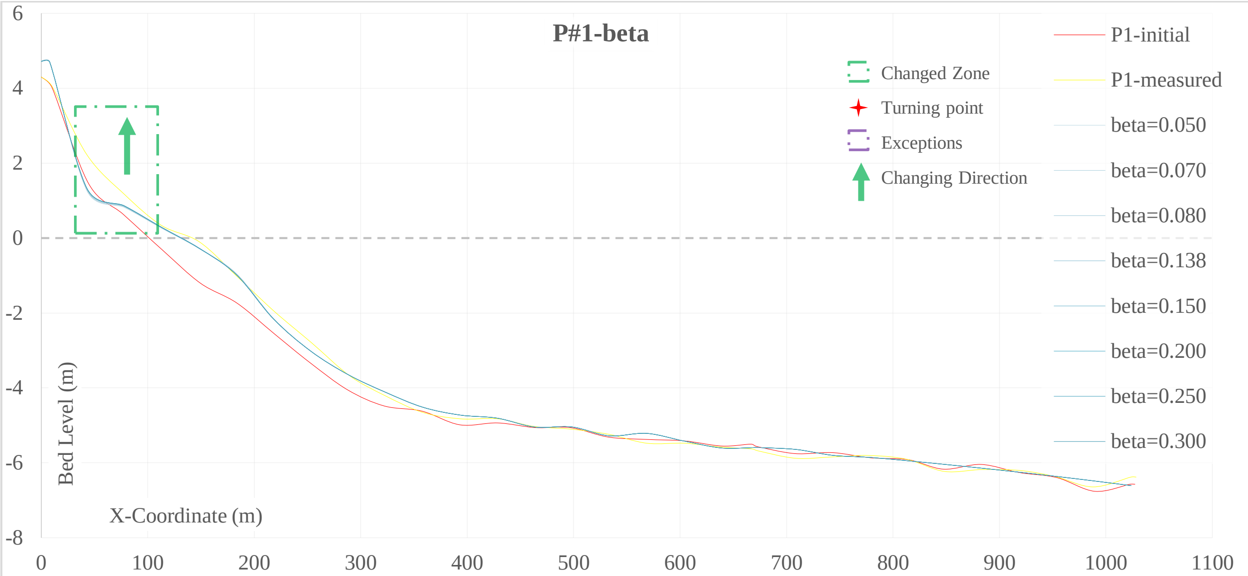

Figure 7. Results of the beta parameter sensitivity analysis in the 7 months (2006.02.20 to 2006.09.23) for profile #1

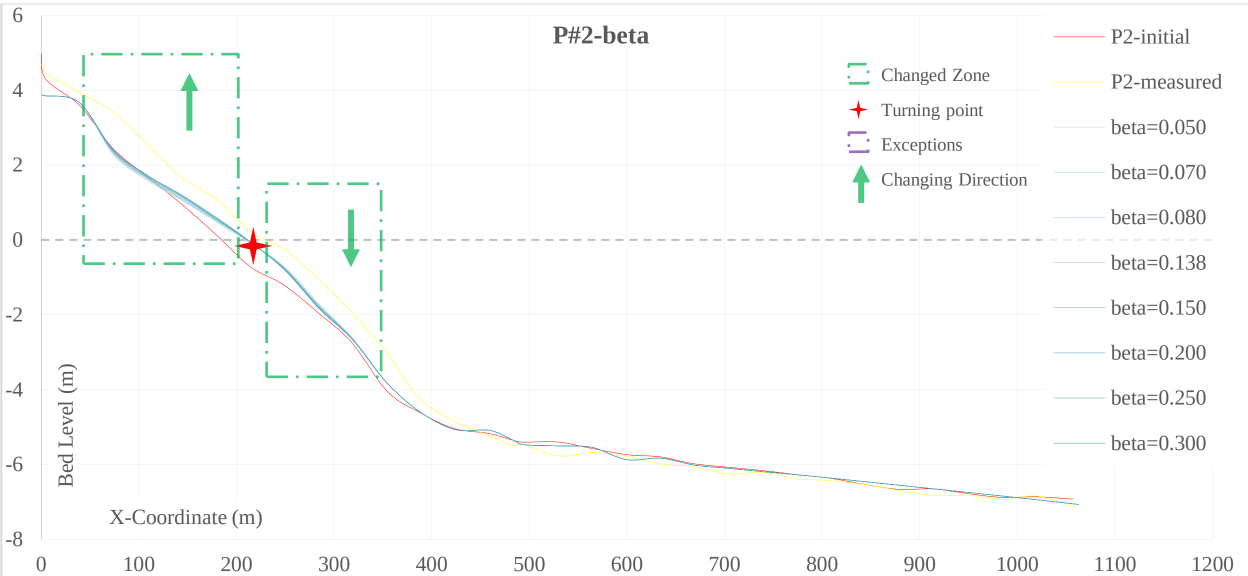

Figure 8. Results of the beta parameter sensitivity analysis in the 7 months (2006.02.20 to 2006.09.23) for profile #2

beta is the breaker slope coefficient in the roller model; the roller model is mainly used to transfer wave-induced setup, return flow, and alongshore current to shore. The lower the beta, the more this transfer takes place [3].

As mentioned, one of the processes that are transferred is the alongshore current, and it induces changes in the shape of the downstream profile (P#2) which the deformation process of the two profiles proves this claim. In general, as shown in Figures 9 and 10, this parameter did not have a significant impact on the behavior of the profiles.

3.4. gammax

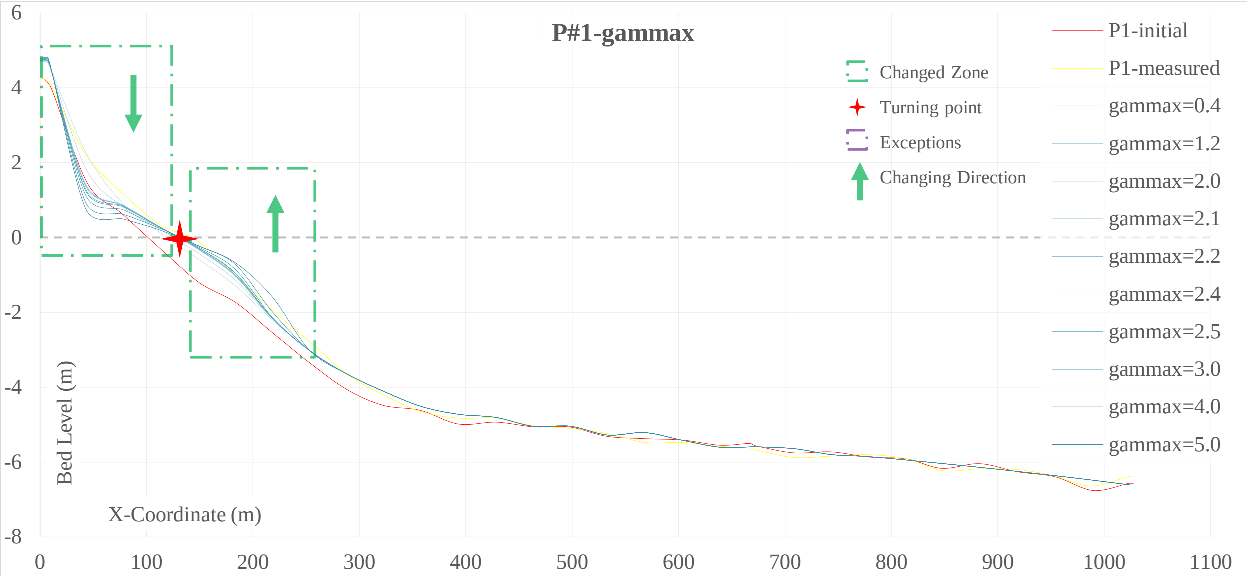

Figure 9. Results of the gammax parameter sensitivity analysis in the 7 months (2006.02.20 to 2006.09.23) for profile #1

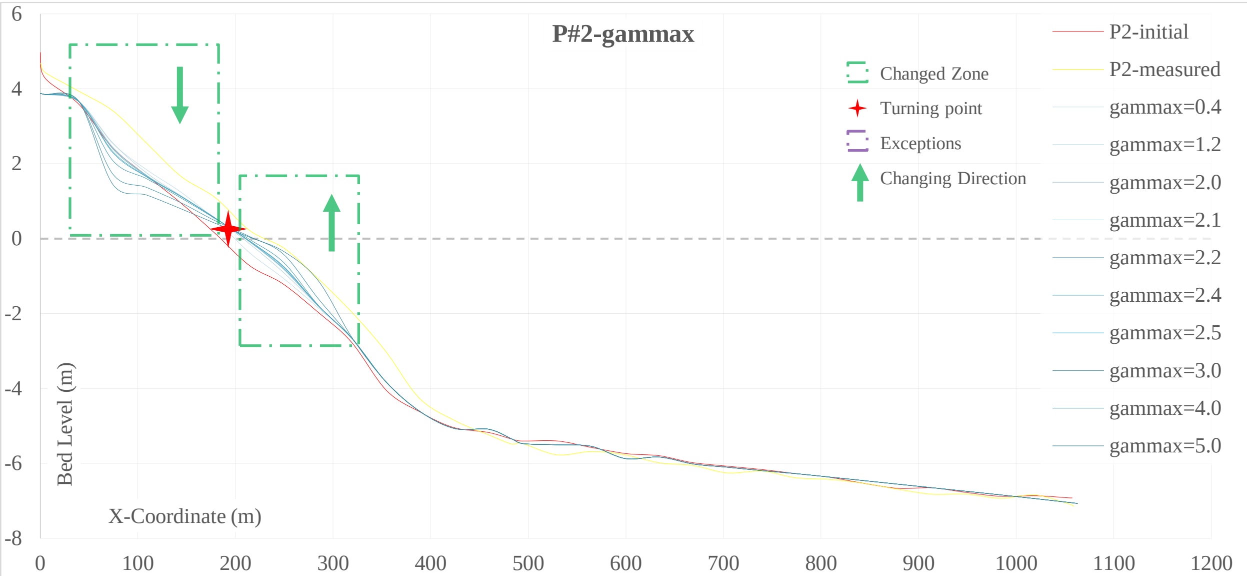

Figure 10. Results of the gammax parameter sensitivity analysis in the 7 months (2006.02.20 to 2006.09.23) for profile #2

This parameter is a deterrent factor that is defined as the ratio of the maximum wave height to the water depth [3].

According to this explanation as well as the figures above, decreasing this parameter reduces the wave height at very low depths; therefore, increasing it, increases the wave height and thus increases the wave energy while reaching the land, which leads to more erosion.

Also, it can be recognized that the increase in this coefficient results in the formation of a bar below the convergence point and a berm above it.

3.5. gamma

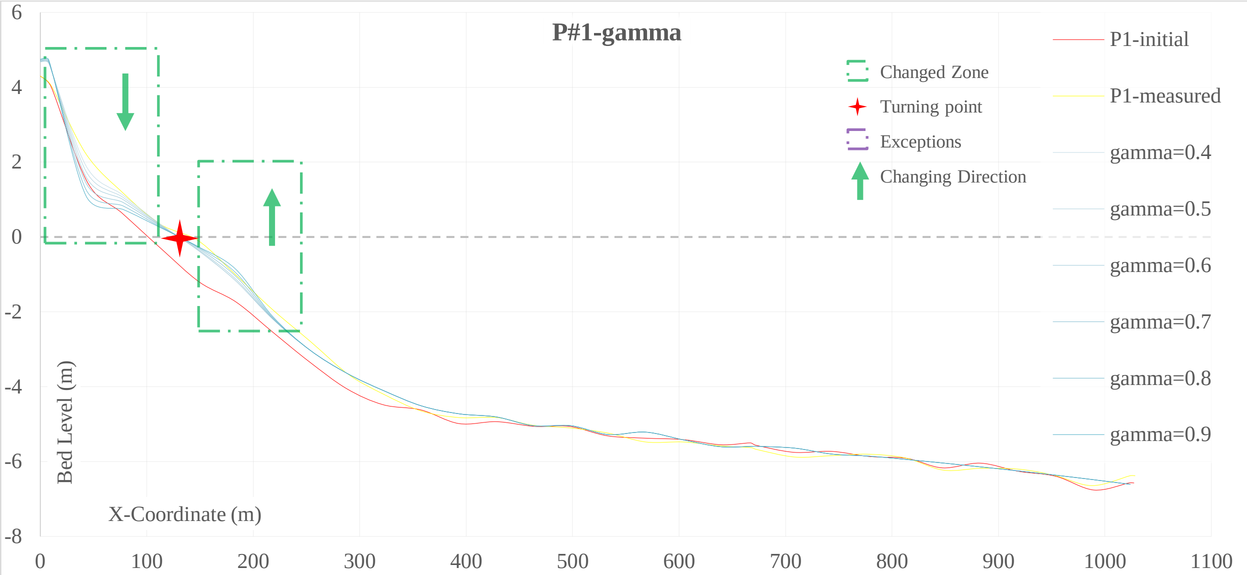

Figure 11. Results of the gamma parameter sensitivity analysis in the 7 months (2006.02.20 to 2006.09.23) for profile #1

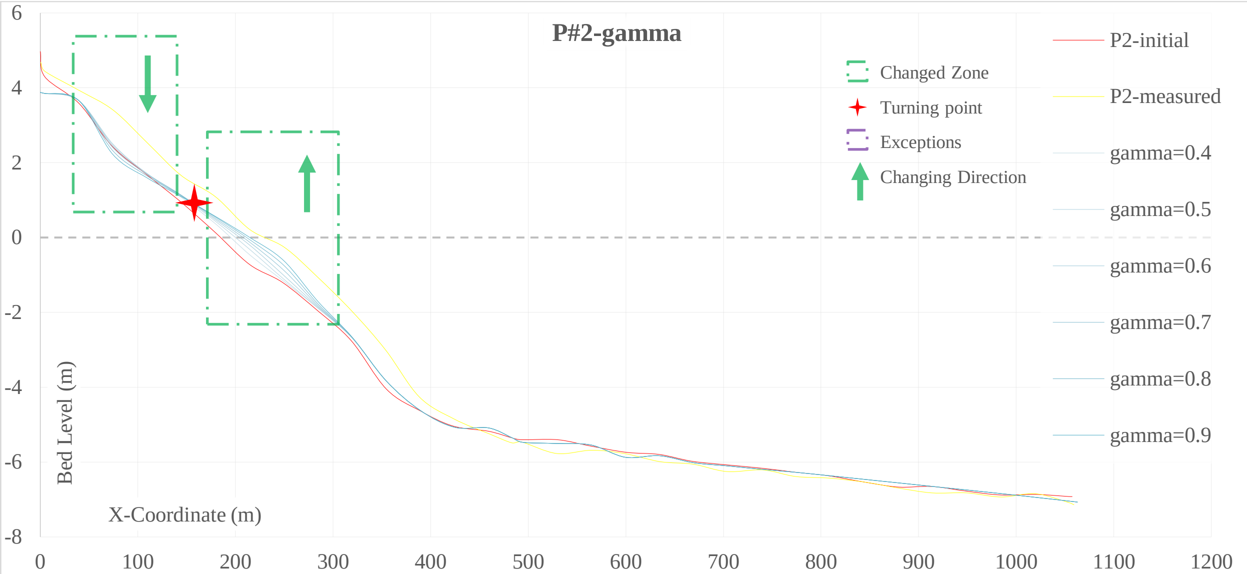

Figure 12. Results of the gamma parameter sensitivity analysis in the 7 months (2006.02.20 to 2006.09.23) for profile #2

gamma is a factor that plays a role in the determination of maximum wave height in wave breaking formulas [3].

According to figures above, the rise in the gamma coefficient in both of the evaluated profiles increases the erosion of the region above the convergence point; This can be supported by considering the equation (1) in which, increasing the value of this parameter raises the wave breaking height so that the wave reaches the land with more energy and causes more erosion and, on its way back, carries the sediments to the area below the convergence point.

3.6. bedfriccoef

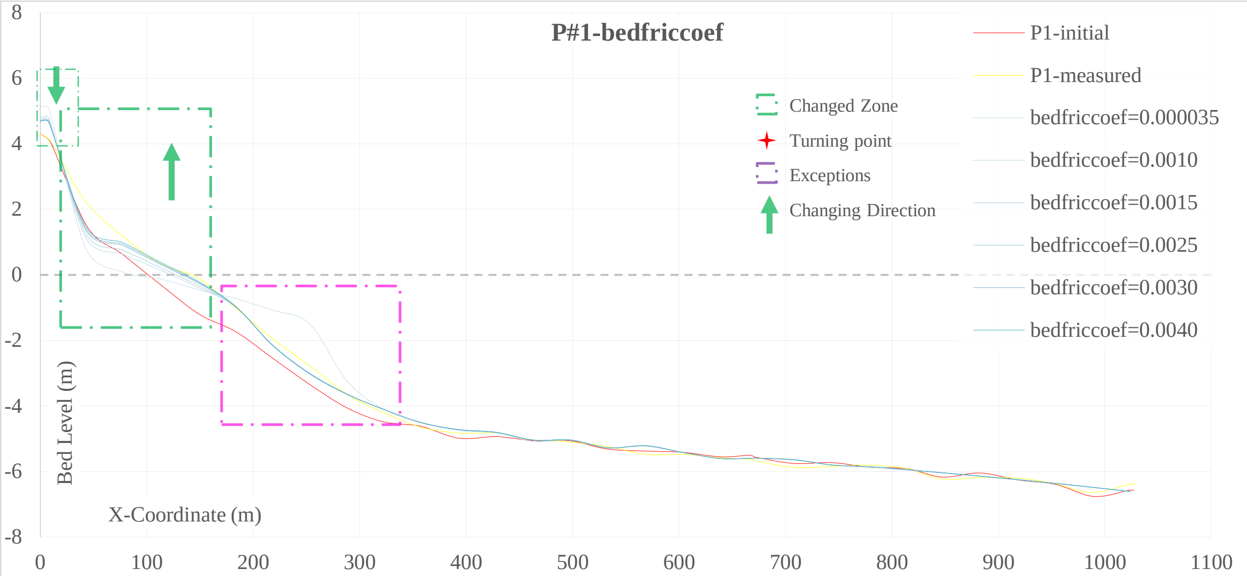

Figure 13. Results of the bedfriccoef parameter sensitivity analysis in the 7 months (2006.02.20 to 2006.09.23) for profile #1

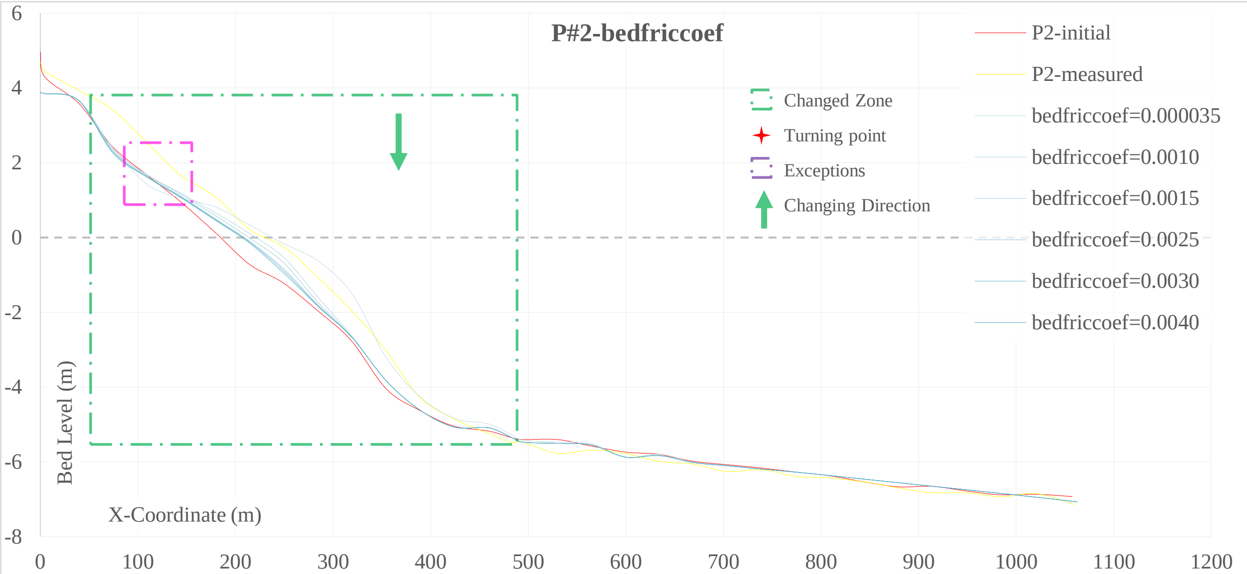

Figure 14. Results of the bedfriccoef parameter sensitivity analysis in the 7 months (2006.02.20 to 2006.09.23) for profile #2

The bed friction factor can be defined by a single parameter (bedfriccoef) for the whole domain, or each cell separately through adding a bed friction file (bedfricfile) [3]. Due to the lack of access to comprehensive data, the first option was used in this study.

Considering the figures above, as the bed friction coefficient increases, the slope of the bed also increases, which corresponds to the characteristics of coarse-grained and fine-grained beaches. However, the profile related to (bedfriccoef=0.000035) exhibited a relatively different behavior (shown in purple dotted rectangles) which can be related to its unrealistic value. Due to the instability of the model in bed friction values above 0.004, the respective results are not presented.

3.7. hmin

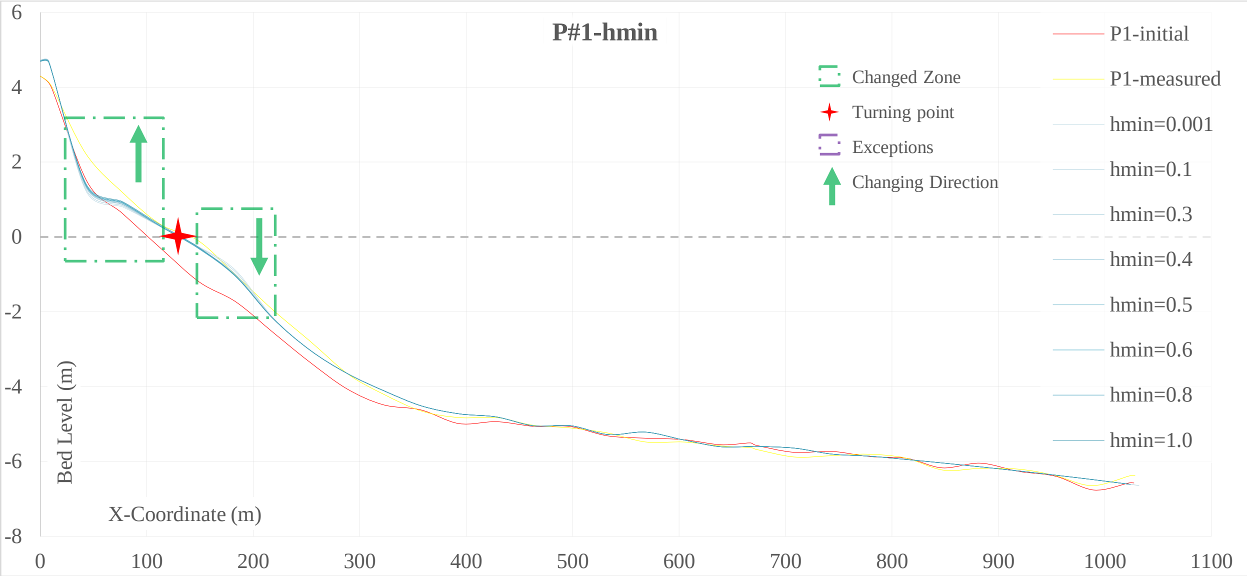

Figure 15. Results of the hmin parameter sensitivity analysis in the 7 months (2006.02.20 to 2006.09.23) for profile #1

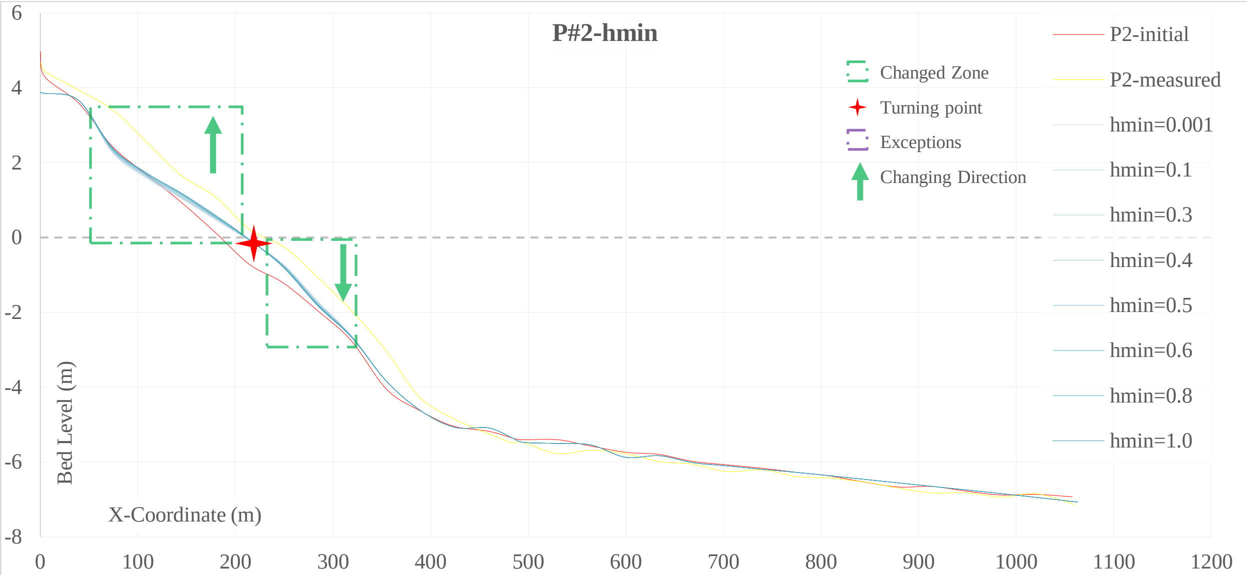

Figure 16. Results of the hmin parameter sensitivity analysis in the 7 months (2006.02.20 to 2006.09.23) for profile #2

The hmin parameter, defined as the "Threshold water depth above which stokes drift is included", prevents very strong return flows or high concentrations [3].

According to this explanation, increasing the amount of hmin increases the range that stokes drift plays a role, and, as a result, we will see weaker concentrations and return flows, as is evident in the behavior of both profiles. As can be seen in the figures above, there is a convergence point in both figures, and as the value of the parameter increases, fewer waves have been able to transfer sediments from the top of the red star to below it.

Of course, due to the very moderate waves at the site, there are approximately no strong return flows in the subject domain, and therefore this parameter had an insignificant effect on the deformation of the profiles.

3.8. wetslp and dryslp

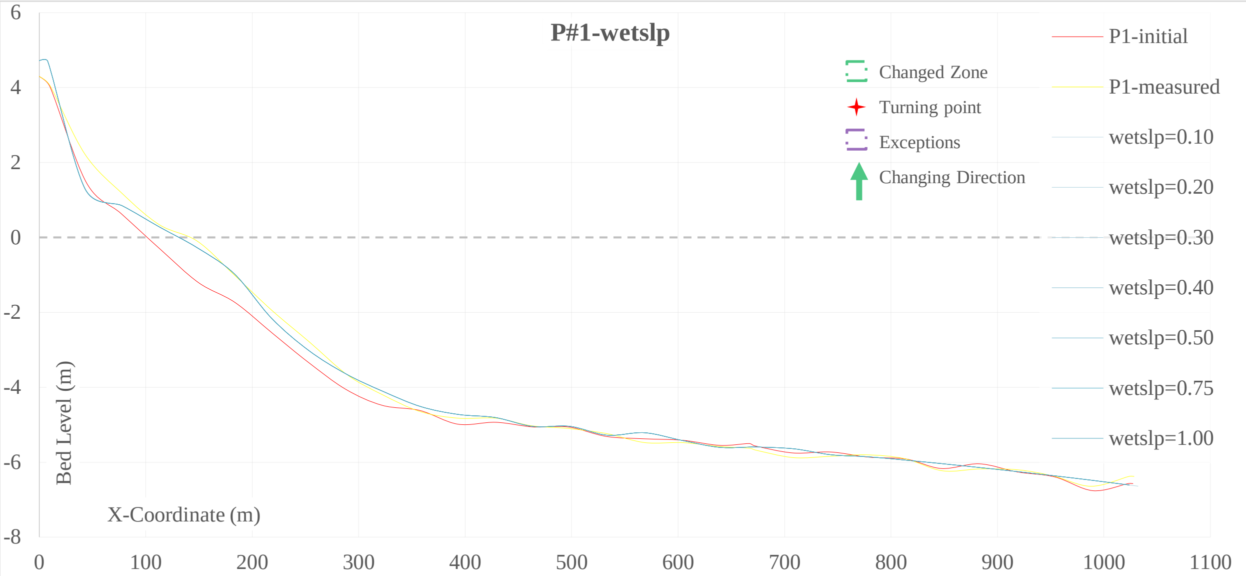

Figure 17. Results of the wetslp parameter sensitivity analysis in the 7 months (2006.02.20 to 2006.09.23) for profile #1

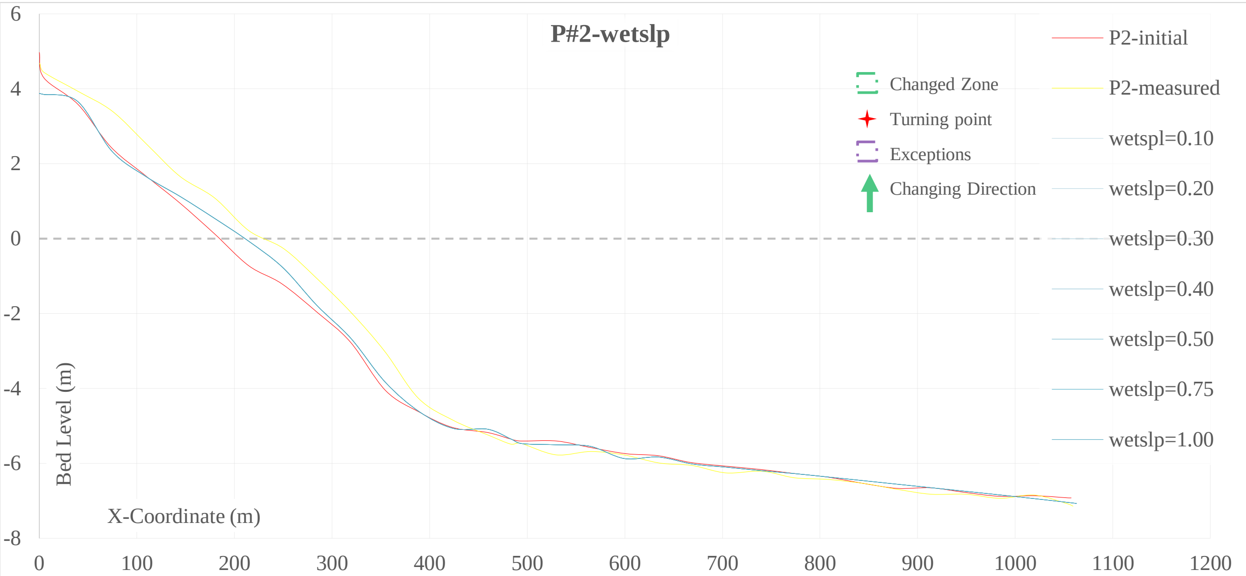

Figure 18. Results of the wetslp parameter sensitivity analysis in the 7 months (2006.02.20 to 2006.09.23) for profile #2

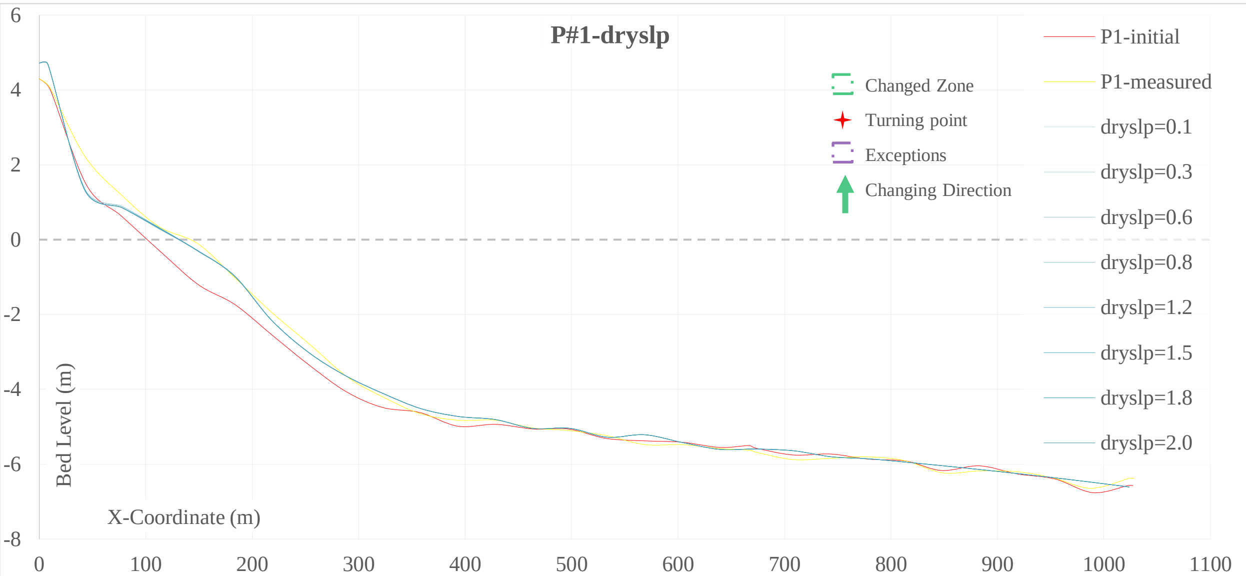

Figure 19. Results of the dryslp parameter sensitivity analysis in the 7 months (2006.02.20 to 2006.09.23) for profile #1

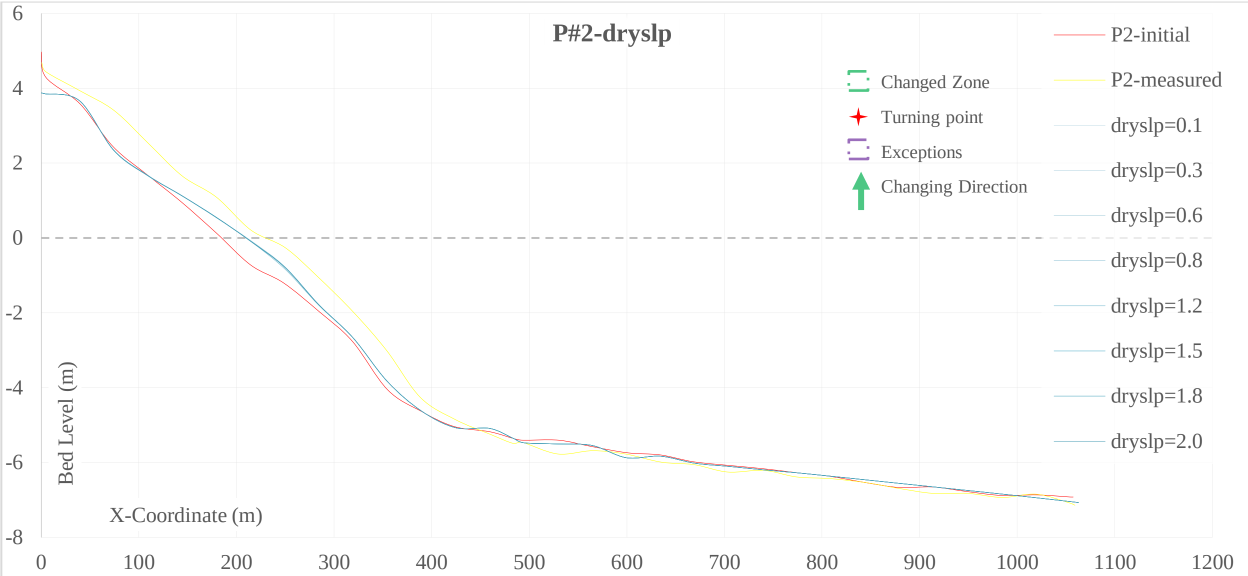

Figure 20. Results of the dryslp parameter sensitivity analysis in the 7 months (2006.02.20 to 2006.09.23) for profile #2

4. Conclusions

Based on previous studies and the present study, it can be said that after passing the calibration step, the XBeach model is capable of modeling on a long-term timescale. However, due to the high number of parameters in this model, it is difficult to choose the perfect calibration factors.

Previously, XBeach was employed to model the Zarabad fishery harbor area in a medium-term timescale using 10 parameters for calibration. Knowing how the profiles behave by changing each parameter, can help accelerate future modelings.

The present study presents the results of more than 150 model runs in the form of selected profiles. A summary of these results can be found in Table 2. As can be seen in this table, changing most parameters (7 out of 10) produced a turning point in the profiles deformation process, and 3 of the factors had an insignificant impact on the profiles.

Of course, changing the particle size, the beach slope, the duration of the modeling, and the change in the energy level of the incoming waves in the area may lead to different results from this study, which can lead to further studies.

Table 2. A summary of the parameters analyzes results.

Parameter	Turning point (Y/N)	Significant impact (Y/N)	Description
facSk & facAs	*Y*	*Y*	Increasing these factors, increased sediment transfer to the shore. skewness factor had less effect on the deformation of profiles that can be due to the fact that the skewed wave can transfer sediments offshore/onshore according to conditions.
alpha	*Y*	*Y*	Increasing this factor, increased sediment transfer to the shore that can be explained by Equation (1). Decreasing this coefficient resulted in the formation of a bar below the red star.
wetslp & dryslp	*N*	*N*	The two critical slope parameters did not have a significant impact on the behavior of the coastal profile due to the rather moderate waves in the area during the study period.
beta	*Y*	*N*	Beta transferred alongshore current toward the shore, which induced changes in the shape of the downstream profile (P#2).
gammax	*Y*	*Y*	Increasing this parameter increased the wave height and thus increased the wave energy while reaching the land, which will lead to more erosion.
gamma	*Y*	*Y*	Increasing gamma increased the erosion of the region above the convergence point which can be supported by considering the equation (1).
bedfriccoef	*N*	*Y*	Increasing bedfriccoef increased the bed slope, which corresponds to the characteristics of coarse-grained and fine-grained beaches. The profile related to bedfriccoef = 0.000035 exhibited a relatively different behavior which could be related to its unrealistic value.
hmin	*Y*	*N*	Increasing hmin disabled most waves to transfer sediments from the top of the red star to below it. Due to the very moderate waves at the site, this parameter had an insignificant effect on the deformation of the profiles.

5. Acknowledgment

The first author would like to thank the Shahrood University of Technology for providing its Computation Center for this study. Also, we acknowledge the use of imagery provided by services from NASA's Global Imagery Browse Services (GIBS), part of NASA's Earth Observing System Data and Information System (EOSDIS).

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